(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 March 2005 (24.03.2005)

PCT

(10) International Publication Number
WO 2005/026801 A2

(51) International Patent Classification⁷: G02B 7/00

(21) International Application Number: PCT/EP2004/009941

(22) International Filing Date: 7 September 2004 (07.09.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/502,334 12 September 2003 (12.09.2003) US

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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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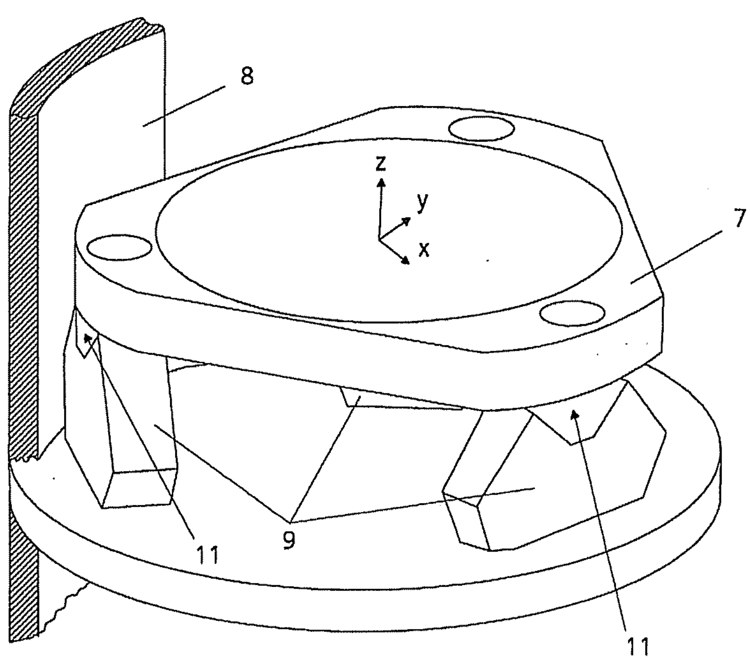
(54) Title: APPARATUS FOR MANIPULATION OF AN OPTICAL ELEMENT



(57) Abstract: The invention relates to an apparatus for manipulation of an optical element (7) in up to six degrees of freedom with respect to a structure (8) via at least three actuator devices (9). The actuator devices (9) each have at least two force-controlled actuators, which each produce an effective force along one degree of freedom, with linking points (11) of the actuator devices (9) acting directly on the optical element (7).

WO 2005/026801 A2

Declarations under Rule 4.17:

— *as to the identity of the inventor (Rule 4.17(i)) for all designations*

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations*

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Apparatus for manipulation of an optical element

The invention relates to an apparatus for manipulation of an optical element in up to six degrees of freedom with respect to a structure via at least three actuator devices. The invention likewise relates to an actuator device for direct linking of an optical element or an optical assembly. The invention also relates to an apparatus for manipulation of an optical assembly in up to six degrees of freedom with respect to a structure via at least three actuator devices. Further, the invention relates to a force-controlled actuator and a force-controlled actuator device.

An apparatus for manipulation of an optical element in up to six degrees of freedom with respect to a structure via at least three actuator devices is known from EP 1 312 965 A1.

Optical elements, in particular mirrors, are mainly manipulated in three degrees of freedom, and piezoactuators, for example, are used for this purpose.

US 5,986,827 discloses a manipulation apparatus for an optical element in three degrees of freedom.

Special applications, such as the accurate positioning of optical elements, of optical assemblies or of a wafer table in projection illumination systems, in particular in the EUVL range, require, however, manipulation or positioning operations in up to six degrees of freedom (both xyz translation and rotation about these axes), with high accuracies at the same time.

Damped force-controlled actuators for damping an optical element in up to six degrees of freedom are known and designated as hybrid actuators. Porter Davis et al. in the article „Second Generation Hybrid D-Strut"; Honeywell Massachusetts Institute of Technology; SPIE Smart Structures and Materials Conference, Feb. 1995, San Diego, California, describes such hybrid actuators. There a Lorentz actuator with a damping system is forming the hybrid actuator. The arrangement of these hybrid actuators in a hexapod configuration is also described. While this configuration focuses the problem of active damping, the present invention relates to actuators or to an actuator system such that almost no parasitic forces are transferred to an optical element, supported or adjusted by the actuators or the actuator system.

The expression degree of freedom should be understood in a mechanical meaning, such that each possibility of cinematic motion of a rigid body is described by an independent coordinate, which represents the respective degree of freedom. Examples for degrees of freedom are translations and rotations as already mentioned.

Actuators which produce movements along one degree of freedom, in particular piezoactuators, are normally linked to the optical element or to the optical assembly, for manipulation. This link must be stiff in the direction of action and must have approximately no stiffness in the remaining degrees of freedom, since the piezoactuator produces displacement forces there. In high-precision applications, this is normally achieved by means of solid body elements, which can introduce undesirable parasitic forces. Sockets are therefore additionally required for compensation purposes, in order to prevent

deformations from being transmitted to the optical element or to the optical assembly. Intermediate elements such as these considerably reduce the high degree of stiffness of the bearing required for precise manipulation, thus disadvantageously resulting in it not being possible to achieve the position accuracies required above.

With regard to the general prior art, reference is made to EP 1 001 512 A2, which discloses force-controlled actuators, in particular Lorentz actuators. The Lorentz actuators described there have a permanent magnet which produces a magnetic field in which an element through which current flows is arranged. The resultant Lorentz force is used to produce a movement or a force between moving parts of the Lorentz actuator.

The present invention is based on the object of providing an apparatus of the type mentioned initially, which allows precise manipulation of optical elements or assemblies in up to six degrees of freedom, with the aid of as far as possible preventing the introduction of undesirable deformations.

According to the invention, this object is achieved in that the actuator devices each have at least two force-controlled actuators, which each produce an effective force in one degree of freedom, with linking points of the actuator devices acting directly on the optical element.

Preferably the effective forces of the actuators of an actuator device are directing in directions of different degrees of freedom of the optical element. Such the effective force of the actuator device, resulting from the forces of the ac-

tuators, may be adjusted within a plane, defined by the effective forces of the actuators, by adjusting the individual forces of the actuators of the actuator device.

Further, the effective forces (caused by the actuators of the actuator device) from the actuator device to the optical element at the linking point between the actuator device and the optical element are such that there are almost no forces perpendicular to the effective forces. This is due to the almost vanishing amount of stiffness in this degree of freedom. However, there is maximum stiffness into the direction of the effective force, caused by the actuators of the actuator device. For achieving the stiffness conditions as mentioned, an actuator according to the present invention is a force-controlled actuator, which produces an effective force in one degree of freedom. This actuator comprises a first and a second element. The elements are moveable relative to each other, and the first element and the second element are mechanically decoupled such that only gas or vacuum is between the first and the second element.

Such a force-controlled actuator, preferably a Lorentz based actuator, results in almost no rigidity, and has almost no damping between the elements. This has the advantages that almost no other forces are transferred from the first element to the second element, except the controlled force in the respective degree of freedom of the actuator, e.g. the Lorentz force defined by the direction and the amount of a magnetic field and the direction and amount of an electrical currant.

To form an actuator device according to the present invention, an element of a first force-controlled actuator as de-

scribed above is coupled via a coupling element to an element of a second force-controlled actuator of the same type. The coupling element can also be an optical element or parts of it, meaning that each actuator of the actuator device is mechanically coupled to the optical element with at least one of its first or second elements. Alternatively a coupling element is directly coupled to the optical element, and each actuator of the actuator device is mechanically coupled to the coupling element with at least one of its first or second element.

In the actuator device according to the present invention, the coupling element is moveable into at least one degree of freedom, if at least one force controlled actuator is actuated. Preferably the coupling element is movable into two degrees of freedom, if both force-controlled actuators of the actuator device are actuated to generate predefined forces.

Further, the linking point of an actuator device can be such that the moving part of the actuators of the actuator device directly contacts the optical element. Here, as already mentioned, the coupling element is the optical element. Preferably the contact is made such that it is essentially a point-like contact, meaning that all actuators of the actuator device affect at the same point of the optical element. However, also other contact geometries are possible like such that the actuators of an actuator device affect at different points of the optical device. If there are more than two actuators in an actuator device, combinations are possible, such that some actuators can affect at the same point and others at other points on the optical element. As mentioned, alternatively or in addition the actuators or at least one

actuator of an actuator device can affect to the optical element via a separate coupling element, which is a part of the actuator device, comprising or forming the linking point of the actuator device to the optical element. Preferably the coupling element is connected with two actuators such that a movement (caused by the actuators) of the optical element can be done in a space (usually a sub-space of the space defined by all degrees of freedom) defined by the degrees of freedom of the two actuators of the actuator device. The separate coupling element has the advantage to form a more point-like linking point between the actuator device and the optical element.

Further, according to the invention, the object is likewise achieved by claims 2 and 18. With regard to the actuator device, the object is achieved by claim 33.

The measures according to the invention provide a precise and rapid manipulation capability for optical elements or optical assemblies in up to six degrees of freedom. The use of force-controlled actuators, which essentially allow the remaining degrees of freedom which differ from the direction of action to be unchanged, mean that there is no need for any intermediate flexible elements or sockets in order to compensate for parasitic forces, thus increasing the overall stiffness of the arrangement, e.g. in the direction of the acting force, and improving the position accuracy.

The invention also provides for three actuator devices to be provided, and for the actuator devices each to have at least two force-controlled actuators which each allow one degree of freedom.

Preferably the actuator devices are arranged relative to each other such that the degrees of freedom of at least two actuator devices are linear independent regarding at least two degrees of freedom given by different actuator devices.

These measures result in the optical elements being mounted in an advantageous manner in an arrangement which allows manipulation or positioning in up to six degrees of freedom. The optical element is in this case mounted without an additional socket, that is to say the actuator devices act directly on the optical element.

It is advantageous for the actuator devices to each have a gravity compensation device.

When no current is flowing, no force is produced in the moving parts of the force-controlled actuators. This is a problem in particular in applications in which the actuators have to bear the gravity force of an object, since a permanent current flow is required for this purpose, and heat is thus also produced continuously. This is highly disadvantageous for use in heat-sensitive apparatuses. Gravity compensation prevents the force-controlled actuators which, so to speak, bear the entire mass of the optical element, from having to have current flowing through them permanently. This advantageously reduces the power consumption, and decreases the resultant thermal energy.

In one development of the invention, it is also possible to provide for the plane which is covered by the linking points of the actuator devices to lie at least approximately on the

neutral plane of the optical element. Preferably the linking points are defining a plane, which is nearby the neutral plane. The planes preferably are arranged such that the maximum distance of the planes within the optical element is smaller than 20% of the maximum thickness of the optical element.

The surface or face within or outside a stiff body, for example an optical element, is referred to as a neutral plane, in which introduction of forces and moments - for example by means of a manipulator or the like - causes minimal deformations on the optical surface. Analogously, for example, the fiber of a workpiece in which there is no stress when the workpiece is bent is referred to as the neutral fiber. The outer and inner fibers are, in contrast, stretched or compressed during bending. The linking points of the actuator devices act directly - without any intermediate socket - on the optical element, in order now to further improve the bearing or the manipulation of the optical element with respect to deformations that are introduced, and the actuator devices act in an advantageous manner on the neutral plane of the optical element.

In one design refinement of the invention, it is also possible to provide for the actuator devices to be replaced for manufacturing purposes by a passive substitute module, with the gravity force directions and action points in the manufacturing phase and during subsequent use matching.

Since the actuator devices can be replaced by a passive substitute module, the optical element can be designed even during the manufacturing phase on the basis of the same force

relationships as during subsequent operation, in particular with regard to compensation for the deformations caused to the optical element by gravity forces. This means that the gravity force during operation is compensated for by a force which acts at an exactly defined point. When an actuator device is replaced by a passive substitute module, the gravity force must once again act at the same point.

It is advantageous for the effective forces of the two force-controlled actuators of the actuator device in each case to pass through a common point, and for the effective force of the gravity compensation device to pass through the common point of the effective forces of the two force-controlled actuators of an actuator device in each case.

In particular, these measures reduce deformations of the optical element caused by moments that are introduced.

Advantages with respect to claims 2, 18 and 33 result analogously to the advantages as already described with reference to claim 1, and from the description.

Advantageous refinements and developments of the invention can be found in the other dependent claims. Exemplary embodiments will be described, in principle, in the following text on the basis of the drawing, in which:

Figure 1 shows a basic configuration of an EUV projection illumination system with a light source, an illumination system and a projection objective;

Figure 2 shows a basic illustration of an apparatus according to the invention for manipulation of an optical element;

Figure 3 shows a basic illustration of an actuator device;

Figure 4 shows a simplified plan view of an apparatus according to the invention for mounting a mirror in a housing of a projection objective;

Figure 5 shows a perspective view of the apparatus according to the invention for mounting a mirror;

Figure 6 shows a perspective view of an actuator device;

Figure 7 shows schematically a force controlled actuator; and

Figure 8 shows schematically an actuator device similar as shown in Fig. 3 and Fig. 6.

As can be seen from Figure 1, an EUV projection illumination system 1 has a light source 2, an EUV illumination system 3 for illumination of a field on a plane 4 in which a structured mask is arranged, as well as a projection objective 5 for imaging the structured mask in the plane 4 onto a light-sensitive substrate 6. An EUV projection illumination system 1 such as this is known from EP 1 278 089 A2.

A capability is normally required in the projection objective 5 for manipulation of optical elements, such as mirrors 7 or

optical assemblies (not illustrated) relative to a housing 8 of the projection objective 5. Appropriate links with actuator devices 9 for the mirrors 7 with respect to the housing 8 of the projection objective 5 are provided for this purpose, (in this context see, in particular, Figures 4 and 5). In another exemplary embodiment, the optical elements could also be manipulated relative to a sensor frame or relative to a measurement structure of the projection objective 5. A measurement structure such as this is known from DE 101 34 387 A1.

Figure 2 shows, in a simplified form, the manipulation of a mirror 7 with the aid of three actuator devices 9 in six degrees of freedom. The actuator devices 9 have force-controlled Lorentz actuators 10, that is to say actuators which are controlled via a force control loop, and which each allow one degree of freedom. The actuator devices 9 are connected to a structure (not illustrated in Figure 2). As is illustrated in Figures 3, 4 and 5, by way of example, this may be the housing 8 of the projection objective 5 of the projection illumination system 1.

Figure 3 shows a basic illustration of the actuator device 9 with a linking point 11 to the mirror 7 and with the two links to the structure, that is to say to the housing 8 of the projection objective 5. The two Lorentz actuators 10 together support two degrees of freedom and are used for manipulation of the mirror 7. In order to minimize the energy consumption of the Lorentz actuators 10, the actuator device 9 additionally has a gravity compensation device 12, which is likewise linked to the housing 8, with a spring element 12 being used for this purpose in the present exemplary embodi-

ment, as an opposing force element in order to compensate for the gravity force of the mirror 7. The forces which occur in the actuator device 9 are advantageously passed from the gravity compensation device 12 and the two Lorentz actuators 10 through a common point, thus minimizing the deformation of the optical surface of the mirror 7, in particular when moments occur. The Lorentz actuators 10 are located on one plane and are at an angle of 90° to one another. The direction of the effective force of the gravity compensation device 12 in the present exemplary embodiment is parallel to the gravity force, and the Lorentz actuators 10 are located symmetrically on both sides of the gravity compensation device 12. In other exemplary embodiments, for example in the case of an obliquely arranged mirror 7, the actuator device 9 need not necessarily be symmetrical.

The linking point 11 in another exemplary embodiment could also be mechanically decoupled from the mirror 7 (for example by force coupling by means of magnetic forces).

Figure 7 shows schematically a force-controlled actuator according to the present invention. The actuator 10 comprises a first element 10a and a second element 10b. The elements 10a, 10b are movable relative to each other. Both elements 10a, 10b are connected to parts A and B, wherein at the application of the present invention one part is an optical element and the other part is a structure like a housing. The first and second elements 10a, 10b are mechanically decoupled such that only a gas or vacuum is between the both elements in the gap 10c. Preferably one element of the elements 10a, 10b comprises a solenoid 10d. If the solenoid 10d is subjected with an electrical current, the gap 10c or a part of the gap 10c

is changed, and the elements 10a, 10b with the parts A, B are moved relative to each other. Preferably the gap 10c is dimensioned such that a movement of +/-300 micrometer is achievable in the direction x and/or z.

Figure 8 shows schematically two force-controlled actuators 10 of the same type, forming an actuator device 9 according to the present invention. Both actuators 10 are of the type as described in connection with Fig. 7, but they are mechanically coupled with a coupling element 15. In the shown embodiment one element 10a of each actuator 10 is connected to a base structure A, while the other element 10b of both actuators is connected to the coupling element 15. The gaps 10c of both actuators 10 are made such that e.g. a movement of about +/-300 micrometer for the coupling element is possible in an arbitrary direction within the xz-plane, such that there is no direct contact between the first and the second elements 10a and 10b of the respective actuators 10.

If the actuator according to Fig. 7 is a Lorentz actuator, the force of the actuator of Fig. 7 acts in the direction of z. Usually a bearing is necessary such the moveable element, say element 10b, is fixed within the yz-plane, the plane perpendicular to the direction of movement. The bearing according to the present invention is not mechanical, since the first and the second elements 10a, 10b of the force-controlled actuator 10 are mechanically decoupled. The bearing preferably is electromagnetic or magnetic.

At the actuator device 9 of Fig. 8 the bearing of the coupling element 15 (which itself could be an optical element) in the xz-plane (the plane defined by the forces of the two

force-controlled actuators, forming the actuator device) is done by magnetic bearing if both actuators are of Lorentz type, e.g. as described in connection with Fig. 7. However, there is no bearing in the yz-plane (the plane perpendicular to the plane defined by the forces of the two force-controlled actuators, forming the actuator device) except if bearing magnets are also used for this direction. Then the first and the second elements 10a, 10b of the force-controlled actuators 10 are mechanically decoupled. Alternative or in addition to the magnetic bearing in the yz-plane a third force-controlled actuator may be connected to the coupling element 15. This third actuator is arranged in a plane other than the xz-plane (the plane defined by the forces of the two force-controlled actuators, forming the actuator device). With such an arrangement a coupling element (which can be an optical element) can be held without mechanical bearing, and can be moved in five degrees of freedom.

Figure 4 shows a simplified plan view of a bearing according to the invention for the mirror 7 in the housing 8 of the projection objective 5. The mirror 7 is manipulated by means of three actuator devices 9, each having two degrees of freedom, relative to the housing 8. The actuator devices 9 are represented by dashed lines since, as can be seen from Figure 5, they are arranged underneath the mirror 7. The actuator devices 9 are arranged distributed at uniform intervals of 120° around the circumference of the mirror 7. The three planes which are covered by the respective force-controlled actuators 10 of one of the actuator devices 9 are preferably but not necessarily parallel to the gravity force and, when seen in the plan view, form a triangle (indicated by the dashed extensions to the actuator devices 9 in Figure 4). The

actuator devices are preferably formed as described in connection with Fig. 8.

Figure 5 shows a perspective view of the apparatus shown in Figure 4. The plane which is covered by the linking points 11 of the actuator devices 9 advantageously lies on the neutral plane of the mirror 7, thus reducing deformations in the mirror surface. In this embodiment, using three actuator devices for the bearing of the optical element 7, there is advantageously no mechanical coupling or connection between the fixed elements and the movable elements of the force controlled actuators. Further, it is important to mention that in the embodiment of Fig. 4, using three actuator devices 9, there is almost no rigidity and damping except there is rigidity into the direct of the forces of the force-controlled actuator devices 9.

Figure 6 shows a perspective view of an actuator device 9 with the Lorentz actuators 10 and with the gravity compensation spring 12. The actuator device 9 is connected to the mirror 7 at the linking point 11 (see Figure 4). The linking point 11 may be formed on a coupling element 15 as described in connection with Fig. 8.

In addition, the position of the mirror 7 is determined by means of sensors (not illustrated).

A passive substitute module can be used during the manufacturing phase in order to make it possible to design the mirror 7 under the same force relationships as during subsequent operation, in order to make it possible to provide compensa-

tion for the mirror deformation resulting from the gravity force (not illustrated).

Patent Claims:

1. An apparatus for manipulation of an optical element in up to six degrees of freedom with respect to a structure via at least three actuator devices, wherein the actuator devices (9) each have at least two force-controlled actuators (10), which each produce an effective force in one degree of freedom, with linking points (11) of the actuator devices (9) acting directly on the optical element (7).

2. The apparatus for manipulation of an optical element in six degrees of freedom with respect to a structure via at least three actuator devices, wherein linking points (11) of the actuator devices (9) act directly on the optical element (7), and the plane which is covered by the linking points (11) of the actuator devices (9) on the optical element (7) lying at least approximately on a neutral plane of the optical element (7).

3. The apparatus as claimed in claim 1 or 2, wherein three actuator devices (9) are provided.

4. The apparatus as claimed in claim 2 or 3, wherein the actuator devices (9) each have at least two force-controlled actuators (10) which each produce an effective force along one degree of freedom.

5. The apparatus as claimed in one of claims 1 to 4, wherein the at least two force-controlled actuators (10) of the actuator device (9) in each case are arranged in a plane at an angle of approximately 60° to approxi-

mately 120°, preferably 90°, with respect to one another.

6. The apparatus as claimed in one of claims 1 to 5, wherein the actuator devices (9) each have a gravity compensation device (12) as an opposing force element in order to compensate for the gravity force of the optical element (7).

7. The apparatus as claimed in one of claims 1, 3 to 6, wherein the three planes which are covered by the respective force-controlled actuators (10) of an actuator device (9) are parallel to the gravity force, and form a triangle in the projection parallel to the gravity force.

8. The apparatus as claimed in one of claims 1 to 7, wherein the actuator devices (9) are arranged essentially uniformly at intervals, preferably at three intervals of 120° around the optical element (7).

9. The apparatus as claimed in one of claims 1, 3 to 8, wherein the plane which is covered by the linking points (11) of the actuator devices (9) on the optical element (7) lies at least approximately on a neutral plane of the optical element (7).

10. The apparatus as claimed in one of claims 1, 3 to 9, wherein the effective forces of the at least two force-controlled actuators (10) of the actuator devices (9) in each case pass through a common point, preferably on the optical element (7).

11. The apparatus as claimed in one of claims 6 to 10, wherein the effective force of the gravity compensation device (12) is essentially parallel to the gravity force, and preferably passes through the common point of the effective forces of the two force-controlled actuators (10) of a actuator device (9) in each case.

12. The apparatus as claimed in one of claims 6 to 11, wherein the effective forces of the at least two force-controlled actuators (10) of the actuator device (9) in each case, and/or the gravity compensation device (12) are/is mechanically decoupled from the optical element (7), preferably via magnetic forces.

13. The apparatus as claimed in one of claims 1 to 12, wherein sensors are provided for determination of a position of the optical element (7).

14. The apparatus as claimed in one of claims 1 to 13, wherein the actuator devices (9) can be replaced, for manufacturing purposes, by a passive substitute module, with the force directions and action points in the manufacturing phase and during subsequent use matching.

15. The apparatus as claimed in claims 1, 3 to 14, wherein the force-controlled actuators are in the form of electromagnetic or magnetostatic, in particular Lorentz actuators (10).

16. The apparatus as claimed in one of claims 1 to 15, wherein the optical element is in the form of a mirror (7).

17. The apparatus as claimed in one of claims 1 to 16, wherein the structure is a housing (8) or a sensor frame of a projection objective (5), in particular of a projection illumination system (1) for microlithography for producing semiconductor components in the EUV range.

18. An apparatus for manipulation of an optical assembly in up to six degrees of freedom with respect to a structure via at least three actuator devices, wherein the actuator devices (9) each have at least two force-controlled actuators (10), which each produce an effective force in one degree of freedom.

19. The apparatus as claimed in claim 18, wherein three actuator devices (9) are provided.

20. The apparatus as claimed in either of claims 18 or 19, wherein the at least two force-controlled actuators (10) of the actuator device (9) in each case are arranged in a plane at an angle of approximately 60° to approximately 120°, preferably 90°, with respect to one another.

21. The apparatus as claimed in one of claims 18, 19 or 20, wherein the actuator devices (9) each have a gravity compensation device (12) as an opposing force element in order to compensate for the gravity force of the optical assembly.

22. The apparatus as claimed in one of claims 18 to 21, wherein the three planes which are covered by the respective force-controlled actuators (10) of an actuator device (9) are parallel to the gravity force, and form a triangle in the projection parallel to the gravity force.

23. The apparatus as claimed in one of claims 18 to 22, wherein the actuator devices (9) are arranged essentially uniformly at intervals, preferably at three intervals of 120°, around the optical assembly.

24. The apparatus as claimed in one of claims 18 to 23, wherein the effective forces of the at least two force-controlled actuators (10) of the actuator devices (9) in each case pass through a common point, preferably on the optical assembly.

25. The apparatus as claimed in one of claims 18 to 24, wherein the effective force of the gravity compensation device (12) is essentially parallel to the gravity force, and preferably passes through the common point of the effective forces of the two force-controlled actuators (10) of a actuator device (9) in each case.

26. The apparatus as claimed in one of claims 18 to 25, wherein the effective forces of the at least two force-controlled actuators (10) of the actuator device (9) in each case, and/or the gravity compensation device (12) are/is mechanically decoupled from the optical assembly, preferably via magnetic forces.

27. The apparatus as claimed in one of claims 18 to 26, wherein sensors are provided for determination of a position of the optical assembly.

28. The apparatus as claimed in one of claims 18 to 27, wherein the actuator devices (9) can be replaced, for manufacturing purposes, by a passive substitute module, with the gravity force directions and action points in the manufacturing phase and during subsequent use matching.

29. The apparatus as claimed in claims 18 to 28, wherein the force-controlled actuators are in the form of electromagnetic or magnetostatic, in particular Lorentz actuators (10).

30. The apparatus as claimed in one of claims 18 to 29, wherein the structure is a housing (8) or a sensor frame of a projection objective (5), in particular of a projection illumination system (1) for microlithography for producing semiconductor components in the EUV range.

31. The apparatus as claimed in one of claims 18 to 30, wherein the optical assembly has at least one optical element and at least one socket element.

32. A projection objective (5), in particular a projection illumination system (1) for microlithography for production of semiconductor components in the EUV range having two or more optical elements (7) which are arranged in a housing (8), with at least one optical element (7) being

mounted such that it can be manipulated with respect to the housing (8) by means of an apparatus as claimed in one of claims 1 to 17.

33. An actuator device for directly linking an optical element (7) or an optical assembly to a structure (8) having at least two force-controlled actuators (10), which each produce an effective force along one degree of freedom and are arranged in a plane at an angle of approximately 60° to approximately 120°, preferably 90°, with respect to one another.

34. The actuator device as claimed in claim 33, wherein the effective forces of the at least two force-controlled actuators (10) in each case pass through a common point, preferably on the optical element (7) or on the optical assembly.

35. The actuator device as claimed in claim 33 or 34, distinguished by a gravity compensation device (12) as an opposing force element in order to compensate for the gravity force of the optical element (7) or of the optical assembly, whose effective force is essentially parallel to the gravity force, and preferably passes through a common intersection point of the effective forces of the two force-controlled actuators (10).

36. The actuator device as claimed in claim 33, 34 or 35, wherein a linking point (11) on the optical element (7) lies at least approximately on a neutral plane of the optical element (7).

37. A force controlled-actuator 10 producing an effective force in one degree of freedom, the actuator 10 comprising a first element 10a and a second element 10b which are movable relative to each other, the first element 10a and the second element 10b are mechanically decoupled such that only gas or vacuum is between the first and the second elements 10a, 10b.

38. A first force-controlled actuator 10 according to claim 37, characterized in that one element 10b is mechanically coupled via a coupling element 15 to an element 10b of a second force-controlled actuator 10 of the same type, both actuators 10 forming an actuator device 9.

39. The actuator device of claim 38, wherein the coupling element 15 is movable into at least one degree of freedom, if at least one force-controlled actuator is actuated.

40. The actuator device of claim 39, wherein the coupling element 15 is movable into two degrees of freedom, if two force-controlled actuators are actuated.

41. The actuator according to one of the claims 33 to 36 with a force-controlled actuator according to claim 37.

42. The apparatus according to one of the claims 1 to 31 with a force-controlled actuator according to claim 37.

43. The projection objective of claim 32 with a force-controlled actuator according to claim 37.

44. Application of a force-controlled actuator according to one of the claims 37 to 40 in an apparatus according to claims 1 to 31 or a projection objective of claim 32.

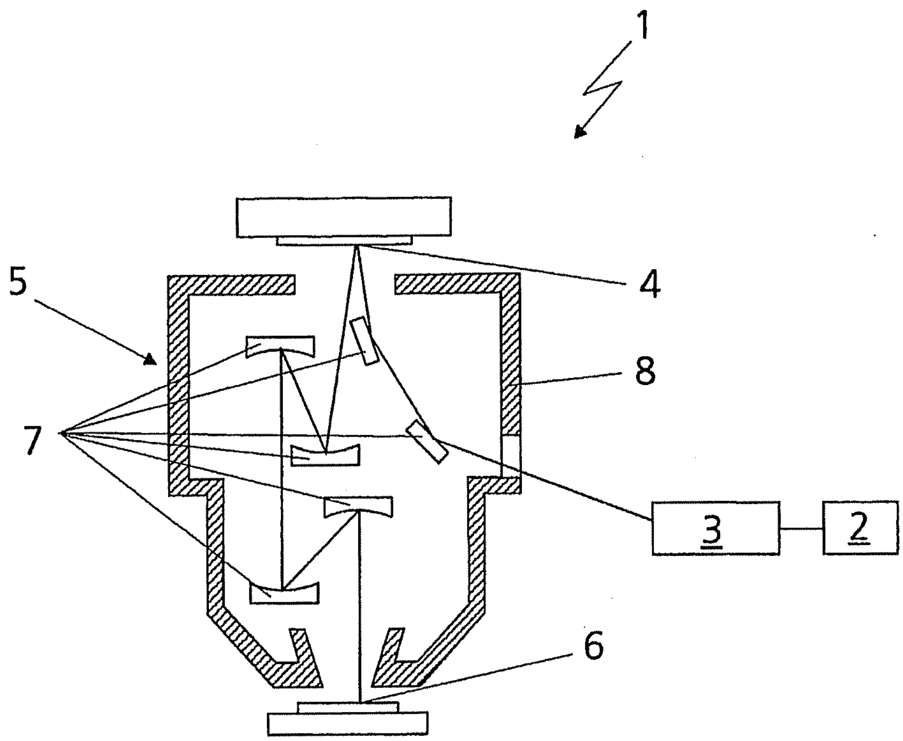


Fig. 1

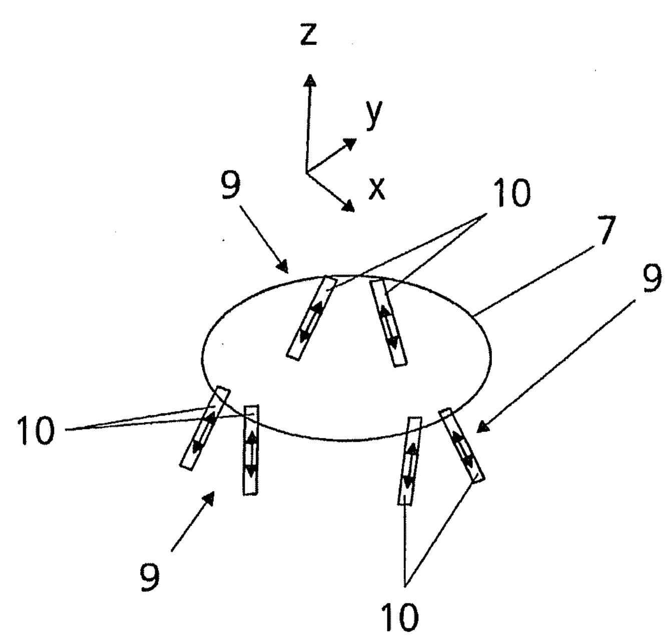


Fig. 2

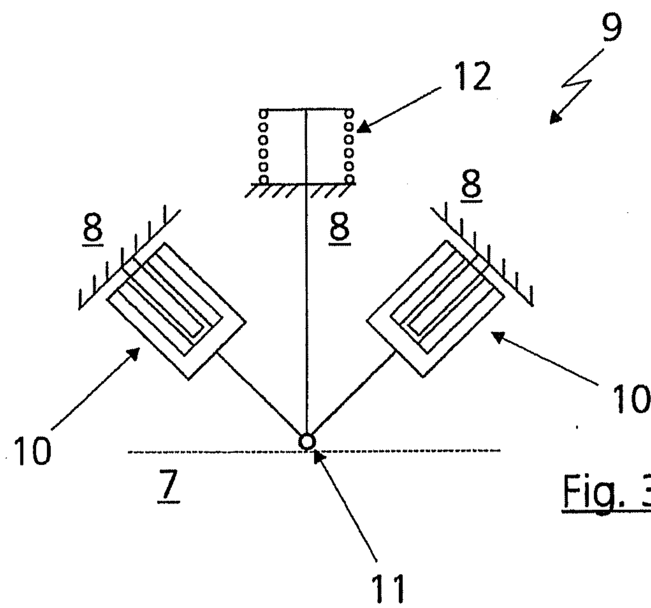


Fig. 3

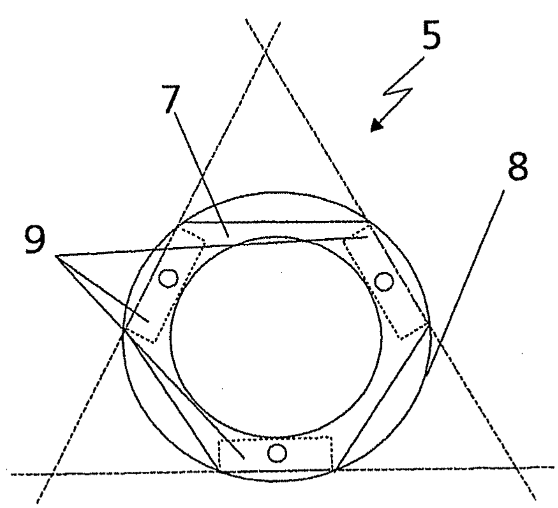


Fig. 4

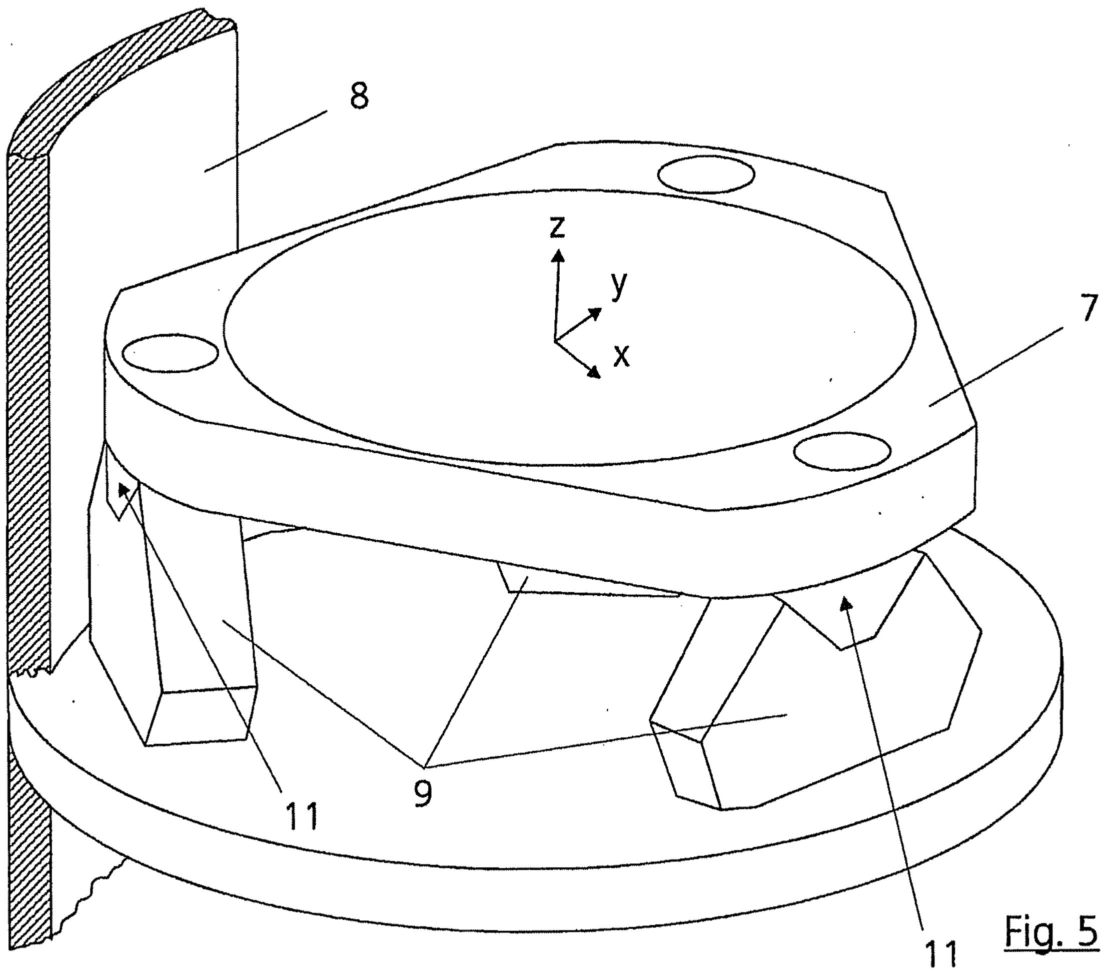


Fig. 5

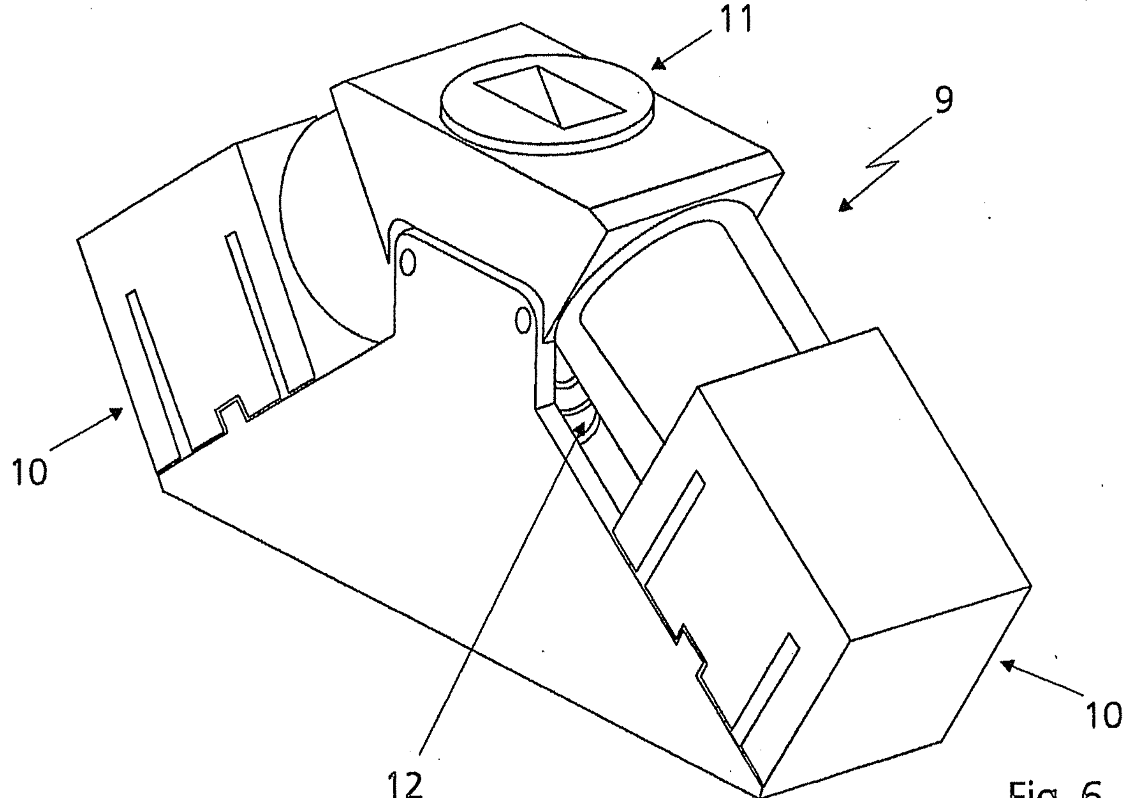


Fig. 6

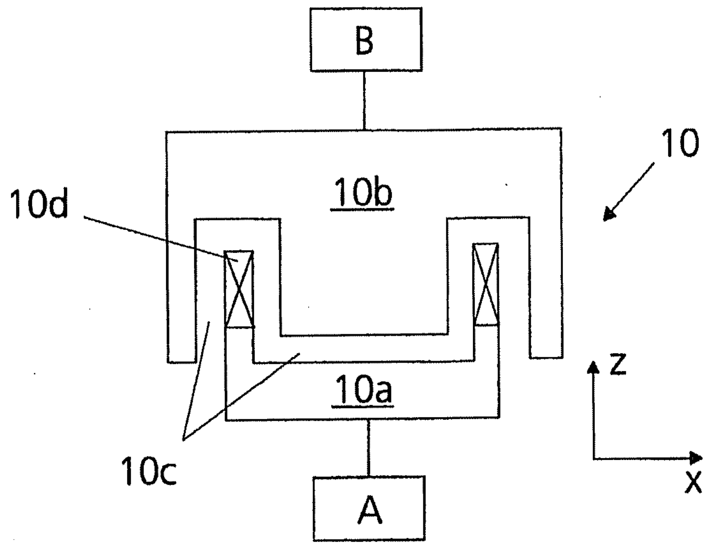

B
10
10b
10d
10a
10c
A
z
x

Fig. 7

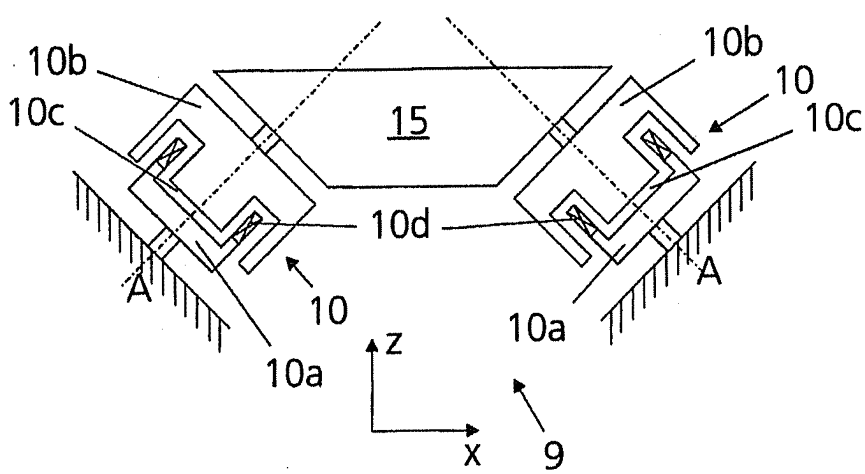

10b
10b
10
10c
10c
15
10d
A
A
10
10a
10a
z
x
9

Fig. 8